Image Quality of CRT Displays and the Effect of Brightness on Diagnosis of Mammograms

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THIS ARTICLE DESCRIBES measurements on two CRT displays designed to determine the image quality of the displays, particularly the display function and the squarewave response. The article also shows the results of an observer performance study, which attempts to determine the influence of image quality on diagnosis in mammography when mammograms are displayed on CRTs at different maximum luminance values. Roehrig et al¹ suggest that there is an influence at least of maximum luminance since the combination of CRT-human observer is a cascaded system, and much of the light emitted by the CRT is not collected by the human eye due to the small numerical aperture of the eye-lens and the low quantum efficiency of the eye's retina (overall collection efficiency about 5×10^{-7}). As a result there will be a "quantum sink" with respect to luminance and observer performance will degrade.²

METHODS

Display Performance Measurements

The two display systems were Data-Ray Model DR 110 (Data-Ray Corp., Westminster, CO) with maximum luminance 140 ft-L and 80 ft-L respectively. The performance measurements included display functions (the relation between out-put luminance and input digital command level) as well as spatial resolution in terms of square-wave modulation. The display functions were determined using the calibrated photometer which is associated with the Dome MD 4 display controller (Dome Imaging Systems, Waltham MA, 02154), and applying the DICOM (Digital Image and Communication Standard) test pattern, ie, a target with an area of 10% of the display's active area, and a background luminance of 20% of maximum as described in reference.³ Special look-up tables of the Dome display controller permitted selection of "Default" and "Barten" settings, even though in the experiment with human observers only the "Default" setting was used. The square wave modulation was measured with a CCD camera as described by Weibrecht et al.⁴ Here square wave patterns from the Nyquist frequency on (line-on-line-off horizontally as well as vertically) down to 0.05 Nyquist frequency were displayed on the CRT and then imaged with the CCD camera at high optical magnification (ie, about 10 CCD pixels per CRT pixel).

Observer Performance Study

Fifty pairs of mammograms were collected from the Tucson Breast Center. Eighteen cases had a single subtle mass, 18 had a single subtle cluster of microcalcifications, and 14 were lesion free. The films were digitized using a Lumisys (Lumisys, Sunnyvale, CA) digitizer with a spot size of 80 microns and a

contrast resolution of 12 bits. They were displayed on the two DataRay DR110 monitors (Table 1). Six radiologists participated as readers. A counterbalanced randomized image presentation order was used with at least two weeks between viewing sessions. The pairs of images appeared on the monitor side-by-side. No image processing (eg, window/level) functions were available during the reading sessions. Readers could view images for as long as desired. Ambient room lights were turned off for this experiment. Viewing time was recorded. For each case, the readers had to report their decisions in two parts. First, readers had to decide if the case was lesion-free or if it contained a mass or microcalcification cluster. They then had to report their confidence in that decision using a six-level rating scale, where 1 = no lesion, definite and 6 = lesion present, definite. If a lesion was reported, readers had to indicate its position on an outline of the breast provided for that purpose. Readers could indicate more than one finding per case.

RESULTS

Display Performance Measurements

The display functions for monitors 1 and 2, with the settings "Default" and "Barten" each are characterized by maximum luminance values of about 140 ft-L (monitor 1) and 80 ft-L (monitor 2). With minimum luminance values of 0.08 ft-L (monitor 1) and 0.03 ft-L (monitor 2) the useful dynamic range is about 1785:1 (monitor 1) and 1454:1 (monitor 2). It is to be noted that these values do not include scatter of light as would be if the SMPTE pattern (Society of Motion Picture and Television Engineers,⁵⁻⁷ had been used to determine the display function.⁸

The square wave modulation for both monitors is similar to those described in ⁴: There is a great difference in the modulation horizontally and vertically. For both monitors, the horizontal modulation at the Nyquist frequency is about 25% while the vertical modulation is about 50%.

This implies, that the shape of a pixel is perhaps an ellipse with the long axis in the horizontal direction and the short axis in the vertical direction. It also implies that the size of an actual pixel is much larger than the size of an addressable pixel,

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Table 1. Basic Specifications for the Data-Ray Monitors Model DR 110

Display Type	Portrait Mode
CRT Size	21" FS
Deflection Angle	90 deg
Active Display Area	11.5" × 15.5"
Phosphor	P-45
Bulb Transmission	52%
Panel	92% and 62%
Resolution	1728 × 2304
Refresh Rate	70 Hz

indicating, that the total number of usable pixels was smaller than the number of addressable pixels: Instead of the addressable pixel matrix of 2000 × 2000 pixels, we estimated only about 1800 × 1800 "detectable" pixels.

Observer Performance Study

The confidence data were analyzed using Alternative Free Response Receiver Operating Characteristic (AFROC) analysis techniques. The area under the curve (A1) values for the six readers are presented in Table 2. There was no statistically significant difference in A1 performance between

Table 2. AFROC A1 Values for the Six Readers

Reader	80 ft-L	140 ftL	Difference
1	.9603	.9655	-.0052
2	.9837	.9843	-.0006
3	.9498	.9538	-.0040
4	.9379	.9744	-.0365
5	.9551	.9727	-.0176
6	.9695	.9663	+.0032

Table 3. Percentages of TP, FN, FP and TN Decisions Across Readers

Decision	80 ftL	140 ftL
TP	83% (179/216)	85% (183/216)
FN	17% (37/216)	15% (33/216)
FP	5% (14/300)	4% (12/300)
TN	86% (72/84)	88% (74/84)

the 140 ft-L (mean = .9695, SD = .009) and the 80 ft-L (mean = .9594, SD = .015) monitors ($t = 1.685$, $df = 5$, $P = .1528$) when tested with a t test for paired observations. The data were also analyzed by examining the percentages of true-positive (TP), false-negative (FN), false-positive (FP) and true-negative (TN) decisions. The results are presented in Table 3. The log odds were calculated and conditions compared using a chi-squared test. The log odds were 3.21 for 80 ft-L and 3.53 for 140 ft-L. The difference was not statistically significant ($\chi^2 = .713$, $df = 1$, $P > .05$).

Viewing time was also recorded and analyzed. Viewing time did differ significantly ($t = 1.994$, $df = 299$, $P = .047$) with viewing time lasting 3.71 sec longer on average on the 80 ft-L monitor than on the 140 ft-L monitor. Viewing times ranged from 6 sec to 99 sec on the 80 ft-L monitor, and from 10 sec to 99 sec on the 140 ft-L monitor.

CONCLUSION

The results indicate that there is an effect of maximum luminance on the performance of the observers, even though, at this time not significant and further studies are indicated.

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